Creativity and Cognitive Development: The Role of Perceptual Similarity and Analogy

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Abstract

We believe that current research in creativity (especially in artificial intelligence and to a great extent psychology) focuses too much on the product and on exceptional (big-C) creativity. In this paper we want to argue that creative thinking and creative behavior result from the continuation of typical human cognitive development and that by looking into the early stages of this development, we can learn more about creativity. Furthermore, we wish to see analogy as a core mechanism in human cognitive development rather than a special skill among many. Some developmental psychology results that support this claim are reviewed. Analogy and metaphor are also seen as central for the creative process. Whereas mainstream research in artificial creativity and computational models of reasoning by analogy stresses the importance of matching the structure between the source and the target domains, we suggest that perceptual similarities play a much more important role, at least when it comes to creative problem solving. We provide some empirical data to support these claims and discuss their consequences.

Introduction

Domain-general creativity is probably the thing that makes human species unique. From kids having fun while constructing a new toy using the old and broken ones (personal or P-creativity, according to Boden's terminology) to Nobel Prize winners who can steer the direction of the human civilization (H-creativity, or big-C creativity): it is all about the surprise, astonishment, and wonder. Despite the understanding of creativity that we may have at an intuitive level, it is no wonder that we have so much difficulty to define it formally and to explore it scientifically. By its very nature it is impossible to predict in what way creativity will manifest itself in the future, and how our construal of it will change given the constant shift of meaning of the concept throughout history. (See Sawyer 2006 for example). Most of the research in psychology and in artificial creativity has been biased towards the H-creativity. In artificial creativity, this resulted in a focus on the creative product within a particular domain (creative writing, painting, music) and coming up with algorithms that would deliver novel and valuable artifacts. In psychology, the consequence was the predominance of the so-called individualistic approach, where extensive studies were conducted of exceptionally creative people's lives, notes, and individual personality traits. The motive was to find some commonalities among them and try to understand the creative process. It is curious to notice the absence of attention in the subject of creativity in the field of developmental psychology (and vice versa). For example, in the critique of one of the rare books that tries to connect these two fields (Sawyer et al. 2003), Simonton (2005) writes:

> "The two key words *creativity* and *development* are not found together very often in mainstream psychological research. […]. For example, the premier journal *Developmental Psychology* has not published an article on the subject of creativity since 1991, […]. Child Development, another top-tier journal, has not published anything specifically regarding creativity for more than 20 years. […] Furthermore, the early pioneers in developmental psychology, whether G. Stanley Hall or Jean Piaget, seem to have had little interest in creativity as a phenomenon. Indeed, most of the key figures in the area of creativity appear to be not developmental psychologists but rather researchers in differential, educational, and organizational psychology." (*emphasis in the original*)

We could say pretty much the same regarding the research in developmental AI and robotics versus artificial creativity, which remain completely disconnected from each other.

The aim of this paper is to articulate a view that sees analogy as a fundamental mechanism of cognitive development, and examine the implications of this view for modeling creativity. The paper is organized as follows. We start in Sec. 2 with a discussion of analogy and creativity. In Sec. 3 we briefly review the computational approaches to modeling analogy and comment on their shortcomings. We continue with Sec. 4 by discussing limitations of the existing artificial creativity systems. In Sec. 5, we present our framework by connecting analogy with Piaget's mechanisms of assimilation and accommodation. In Sec. 6, we discuss some implications of this framework for the role of similarity in analogy and creativity, and in Sec. 7 we summarize our main conclusions.

Analogy in Creativity

Analogy has been recognized as a key mechanism of creativity (Bonnardel 2000; Gordon 1961; Hofstadter 1995, 2001; Koestler 1964; Nersessian and Chandrasekharan 2009; Okada et al 2009). However, one must distinguish (at least) between **two modes** of analogy. On one hand, analogy refers to 'seeing one thing as another', and on the other hand it refers to the process whereby the structure and the attributes of one object or situation (the source) are mapped to another object or situation (the target). This latter mechanism seems contrary to creativity according to many accounts (Indurkhya 2010) and so it needs a little elaboration.

Every conceptualization (of objects, situations, visual images) involves loss of some potential information: potential differences are ignored between two objects that are put in the same category, and potential similarities are ignored between two objects that are put in different categories. The concepts and categories, and their underlying cognitive structures that naturally evolve through a cognitive agent's interaction with the environment, reflect the experience and the priorities of the agent. The information that is retained in the conventional conceptualization is the one that has been useful to the agent in its phylogenetic and ontogenetic past. So, as long as one stays in the familiar domain (in which the conventional conceptualizations are very useful), and the problem at hand does not require the potentially lost information, reasoning from conventional operations and conceptualizations may be very efficient. However, as soon as the problem requires new information, the existing conceptualization stops being useful, and a new conceptualization becomes necessary. In such situations, analogy, as it is traditionally construed, becomes a hindrance because it reinforces the existing conceptualization, and metaphor becomes a very useful heuristic. (See also Gordon 1961; Indurkhya 1992, 1997)

If we follow this argument, analogy, in its traditional sense at least, which is based on structural similarities, turns out to be an anathema to creativity. The reason is that analogies are based on mapping the structure or attributes of the source to the structure and attributes of the target. So an analogy, which is based on the existing conceptualization of the source, will retrieve sources that are similar to the structure, thereby further strengthening the existing conceptualization of the target. In some cases, this may be enough to solve the problem, e.g. by bringing to the forefront some of the less prominent attributes of the target. But if the problem could not be solved because of needing new information, then an analogy-based approach will not be very useful.

Computational Models of Analogy

Much of the research on computational modeling of analogy has worked with what might be characterized as mapping-between-existing-representations paradigm, where there are given representations of the source and the target, and various algorithms are applied for mapping parts of the source to parts of target. Models differ from one another with respect to whether mapping between relations is preferred over attributes; or whether an incremental or a distributed approach is applied to compute the mapping (Gentner 1983; Falkenhainer, Forbus and Gentner 1989; Holyoak and Thagard, 1989; Hummel and K. J. Holyoak, 1997, 2003). All these approaches have severe limitations in that they cannot model emergence of new structure, which is very crucial as far as creativity is concerned. (For a good critical overview see Chalmers, French and Hofstadter 1992). Though these models do capture a certain aspect of creativity in noticing new connections between existing knowledge, and in importing novel hypotheses from the source to the target, they do not produce a paradigm shift of Kuhnian kind. In this regard, models based on corpus-based analyses and distributed representations seem more promising (Sun 1995; Veale and Hao 2008), but so far they are limited to linguistic metaphors.

In contrast, some other approaches have focused on the process of representation building itself, notable among them being the work of Hofstadter and his colleagues. In this paradigm, the appropriate representations of the source and the target and the mapping between them evolve together by parallel processes that interact with each other (Hofstadter 1995; Mitchell 1993). This approach comes closer to being able to model creativity, for often creative insights emerge from applying a concept to an object (or a low-level representation of it) that is not habitually associated with it. In our earlier work, we have formalized this process (Indurkhya 1992), and have applied it to model creativity in legal reasoning (Indurkhya 1997), but clearly much more work remains to be done. Moreover, in real-life, a number of different cognitive processes may act in consort to generate a creative insight, modeling of which may require hybrid architectures (Nersessian and Chandrasekharan 2009; Indurkhya and Ogawa 2012).

Artificial Creativity Systems

As we hinted in the introduction, research in creativity (usually conducted within psychology), since its inception, has shown a bias towards exceptional individuals, that is the big-C creativity. "Big-C" is a shortcut for describing creative deeds that are recognized as such widely by the society, as opposed to what is usually called "small-c creativity": creative solutions/products which are new to the person producing them. Consequences of these views were felt in the research in Artificial Creativity (AC) and Computational models of Metaphor and Analogy (CMA) where, often, the existence of creativity and analogy modules was hypothesized. Attempts to model those modules were made and virtually all of them aimed at big-C creativity (composing music, writing novels, painting…) as opposed to mundane creativity. In (Stojanov 2012) we give an extensive review of the approaches in AC research. Below, we only mention the main conclusions. What can be said about the vast majority of existing Artificial Creative systems?

-Virtually all of them focus on the product (a consequence of the **product generating paradigm** in which they are working) rather than on the process. Thus, we may call this approach **top-down** or **product-first** approach;

- Most of them are given, in advance, a **detailed (hard-coded) description of the domain**. This can be: language syntax, narrative structure, and some semantics for **artificial prose writers**; musical notation and rules for **artificial composers** and **creative interpreters**; basic drawing primitives for **artificial painters**; basic mathematical operations, a lot of search heuristics with evaluation functions, and big knowledge/fact base for **artificial scientists**;

-All these AC systems appear to be **closed systems** in the sense that there is no way to appreciate, and build upon, the feedback from naïve (or not) observers;

-None of these AC systems are **socially embedded** except, in a certain sense, via their designers who themselves receive feedback from the audience and eventually make the necessary changes in their programs;

-Virtually all of the researchers within AC looked for inspiration into the existing theories of the domain in which their systems are supposed to be creative: literary and narrative theory, music theory, visual arts, etc. This goes counter to our intuitions and the empirical facts that many artists and scientists report that actually combining domains (in which they not need be widely recognized but simply familiar enough) has resulted in some of their most creative outputs.

On a more abstract level (and with risk of oversimplification) we could say that the majority of AC systems to date quite resemble the generic architecture of a GOFAI expert system from the '70s and '80s of the last century.

Given the dominant approaches to computational models of analogy (i.e. focusing on relational matches between two hardcoded representations), it is probably not surprising that although (as mentioned in section 2) analogy is often seen as a key factor to the creative process, we rarely see AC systems that use analogy. (However, see Zhu and Ontanon 2010 for an example).

Analogy in Cognitive Development

Reasoning by analogy is sometimes seen as a pinnacle of cognitive development. Goswami in (Goswami 2007), for instance, notes that in Piaget's account, analogical reasoning occurs only in adolescence during the formal operation stage. In contrast, Goswami goes on to review a number of research results that show that analogy is far more pervasive in cognitive development, and occurs much earlier, i.e. even in 3 and 4 year olds. Goswami argued that children in some of Piaget's experiments were not able to solve a relational analogy problem because they were not familiar with the causal relations among the objects (e.g**. 'bicycle : handlebars :: ship : ?'**, handlebars are used to guide the bicycle in the same way the **ship's wheel** is used to steer the ship). However, a close look at Piaget's numerous studies reveals that he has also noted the onset of analogical thinking manifested as a sensorimotor schema at a very young age:

> "At 1;4(0) L. tried to get a watch chain out of a matchbox when the box was not more than an eighth of an inch open. She gazed at the box with great attention, then opened and closed her mouth several times in succession, at first only slightly and then wider and wider. It was clear that the child, in her effort to picture to herself the means of enlarging the opening, was using as 'signifier' her own mouth, with the movements of which she was familiar tactually and kinesthetically as well as by analogy with the visual image of the mouths of others. It is possible that there may also have been an element of 'causality through imitation,' L. perhaps still trying, in spite of her age, to act on the box through her miming. But the essential thing for her, as the context of the behaviour clearly showed, was to grasp the situation, and to picture it to herself actively in order to do so." (Piaget 1962, p. 65; see also Piaget 1977)

We included this long quote here for it illustrates that Piaget was fully aware of the key role played by analogy and its various manifestations in cognitive development as early as sixteen months[1]. Accordingly, in the framework

[1] These differences (Goswami vs Piaget) may stem from Piaget's idiosyncratic approach to research: he was not trying to study particular

that we propose here, cognitive development is a series of small creative leaps where a cognitive agent internalizes its interaction with the environment. Using the standard language of cognitive science or artificial intelligence, we can see these internal constructs as the agent's representations of the environment, or, to be more accurate: representation of the agent's embeddedness in that particular environment. Initially, these representations are entirely expressed in terms of the innate Piagetian sensory-motor schemas. That is, we can look at the innate schemas as **the source domain** for a metaphorical description of the agent's environment (the unknown **target domain**). Through the processes of assimilation (current metaphors can explain new experiences) and accommodation (re-conceptualization of the source domain is needed in view of new experiences), as well as spontaneous reorganization of the internal schema space (for example, by finding similarities and connections among distant internal schema subspaces) cognitive agents change themselves and their environments (physical, social, linguistic). (See also (Indurkhya 1992)). They need to master motor skills, language, social conventions, norms, and so on. This maturation process consists of many creative acts, driven by our genetic heritage as well as the micro and macro social context. The growth continues throughout the lifetime of the individual and, in some cases, particularly creative individuals may question some of the norms and conventions of their culture, and may impact significantly some particular established domain (arts, sciences, religion) or even create entirely new domains. The point here is that creativity is understood as a continuum and not as a binary ('yes' or 'no') attribute. It is also the driving force behind our cognitive development and it relies on more basic cognitive processes described above. An initial outline of this approach can be found in (Stojanov 1999) and its partial implementation in context of mobile robot learning can be found in (Poprcova, Stojanov and Kulakov 2010).

If what we suggest is plausible, the dominant approaches in artificial creativity and computational modeling of analogical (metaphorical) reasoning will have to be re-evaluated and probably fundamentally changed.

modules or faculties (such as reasoning by analogy, for example) but as an acute observer he was trying to offer the best explanation that may account for certain types of behavior at certain age groups. We would like to offer the following speculation: if we were to ask Piaget about analogical reasoning and how/when it develops he might say that there is no particular age when children begin to reason by analogy. What happens is a gradual progression that starts from objects being understood only in terms of the sensorimotor schemas in which it is involved; an object 'is for something' and there is no independent representation of them. Their properties remain contextual (and not fixed) and hence reasoning about relations among objects will neither be stable nor be consistent, especially at an early age of 4 or 5. Piaget thus, we might assume, hesitated to call this reasoning by analogy, reserving the term for his formal-operations stage when abstract object and relation representations are fully developed and available for conscious manipulation. Later in the paper we offer an alternative framework for interpretation of Piaget's theory by adopting a broader construal of what is meant by 'analogy'.

Similarity and Analogy in Creativity

In cognitive development, it has been noted that younger children tend to focus on surface-level similarities, and only later they take into account relational and structural similarities. For example, Namy and Gentner (Namy and Gentner 2002) remark:

> "Children up to five years go for perceptually similar objects. Clearly, then, a large number of studies have converged to demonstrate that perceptual properties such as shape loom large in children's responses on categorization tasks. This evidence suggests that children rely on shape or other salient perceptual features—perhaps even to an extent that seems detrimental to their acquisition of conceptually coherent object categories." (p. 6)

Apart from Piaget's theory of cognitive development which we mention above, other theories can be re-casted too as series of small P-creative leaps during which conventional conceptualization arise. Karmiloff-Smith (Karmiloff-Smith 1986, 1992) proposes the representational redescription model, which consists of an endogenously driven "process by which implicit information in the mind subsequently becomes explicit knowledge to the mind" (Karmiloff-Smith, 1992 p. 18). The process can be likened to Piaget's stages from early sensorimotor schemas (which too are endogenously driven to be executed) to the final stage of formal operations where the subject deliberately/consciously manipulates different abstract schemas. Karmiloff-Smith's developing agent goes through four phases, where the first one (I) is characterized by implicit/behavioral knowledge/skill representations applied to certain task. These are rather detailed and task specific, and are not available for conscious manipulation by the subject. The next three phases E1, E2, E3 represent the emergence of more and more explicit, abstract, and finally (E3) verbalizable representations. These representations lose many specific details compared to the first (I) phase representations, but become more flexible/reusable, and declarative. As such, they also become members of a huge library of source analogies which can be applied to different problems.

Barsalou and Prinz's (Barsalou and Prinz 1997) theory of mundane creativity in perceptual symbol systems (Barsalou 2008) also comes close to the picture we want to paint here. Their theory of cognitive development focuses on the formation of perceptual symbols, which originate from the perceptual input (across all modalities) during an agent's sensorimotor interaction with the environment. By the processes of selective attention, the subject focuses on some aspects of the entire perceptual input, filtering out alternative potential aspects to a large extent. These perceptual aspects are transferred into the long-term memory, and in essence can be seen as concepts that can be recalled by similar perceptual input. In the language that we have adopted here, this would correspond to the emergence of conventional conceptualization. A creative insight then would happen when an agent uses a non-conventional perceptual symbol or symbols to perceive the given object/situation/scene.

In creativity research, it has been widely recognized that similarities play a key role in the generation of new ideas (Koestler 1964; Ward 2011). Although surface similarities are often found to influence memory access and recall (Barnden and Holyak 1994), most of the research has focused on semantic aspects of the similarity, like structural alignment, for these are considered to be more helpful in problem-solving and learning. In fact, surface similarities are often thought to be distracting (Faries and Schlossberg 1994). A number of other creativity researchers, however, point out that focusing on structural similarities reinforces conventional way of viewing a given situation, and the crux of creativity lies in breaking the conventional structure, and conceptualize the situation in a new way (de Bono, 1975; Gordon 1961; Rodari, 1996]. In this process, surface similarities can act as cues to connect two (conventionally) unrelated objects in a new way.

In a recent series of papers Peter Caruthers and his collaborators (2002, 2006), Picciuto and Carruthers (2012) explore the phenomenon of *child pretend play* and its connection to creative behavior from an evolutionary perspective. For him (Carruthers 2002) "Creativity […] will normally manifest itself in new types of behavior, going beyond mere re-applications of established scripts or action-patterns. And creativity itself is constituted, in part, by a capacity to combine together ideas in novel ways in abstraction from any immediate environmental stimulation". Also "When applied as a predicate of individuals, 'creative' will be a matter of degree, of course—a person or creature can be more or less creative by engaging to a greater or lesser extent in creative behaviors and creative thought-processes" (*idem*). Pretense play seems to us an excellent example where children enjoy considering one object/situation as another based virtually always on superficial/perceptual similarity.

Some of our recent empirical studies further support this view. In one set of studies (Indurkhya et al. 2008; Ojha and Indurkhya, 2009, 2012 *to appear*), we have found that low-level perceptual similarities — that is, similarities with respect to texture, shape, color, etc. determined algorithmically — facilitate creation of conceptual features and conceptual similarities. In another study (Indurkhya and Ogawa 2012), we focused on the creative process involved in connecting two pictures by painting another picture in the middle. This technique was involved in *four Infinite Landscape* workshops conducted by a visual artist at Art Museums in Japan and Europe 2007-11. Based on the artist's verbal recollection of the ideas that occurred to him as he drew each of the connecting pictures, we identified the micro-processes and cognitive mechanisms underlying these ideas, and found that surface features, contrast, and meaning deconstruction play major roles in the generation of new ideas.

What can we conclude from the above? First, traditional models of analogical reasoning that prefer relation over attribute mappings may be useful when we have to solve a novel problem in a domain with high structural similarities to some familiar domain. The solutions that may result from this process will rarely be deemed creative and will reinforce traditional conceptualizations of both domains. On the other hand, we may have no or little knowledge of the deep structure of the target domain (for example, in early cognitive development). In these cases, perceptual similarities may lead to novel conceptualizations (of both source and target domains) and highly creative solutions or products.

Conclusions

We have presented a view here where analogy represents a core process in human cognitive development. We have argued that creativity in human agents represents a continuum: from everyday/mundane/P-creativity to the big-C creativity. Accepting the view that analogy is crucial for creativity, we attempted to make the case that superficial (attribute) similarities may actually lead to more original solutions or products. Structural analogies only reinforce the conventional conceptualization, which may be a hindrance in case the problem at hand requires information that is not normally a part of this conceptualization. We have re-casted Piaget's theory of cognitive development by describing assimilation and accommodation as progressive reasoning by analogy starting from early analogizing in terms of sensory motor schemas, to analogies in mature cognitive agents who have developed object representations. Within this framework for creativity, we gave a critical overview of today's artificial creativity models, and provided some empirical support for the claim that surface-level or perceptual similarities may play a more central role in creativity than has been supposed so far.

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